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ABSTRACT

The pelagic zooplankton population in Williston Reservoir was sampled at five sites during the summer of 1999 to determine population composition, density and biomass. This was conducted as the first year of a projected two year monitoring program initiated to investigate the limnology, and determine the current trophic status of the reservoir. Upon completion the results will be compared to previous Williston Reservoir limnological studies to determine the extent and magnitude of any changes in the reservoir's productivity, or trophic status, which will have implications to reservoir fish populations. This report summarizes the zooplankton data collected during the 1999 field season.

Williston Reservoir was formed by the impoundment of the Peace River in 1968, and with a surface area of 1,779 km^2 is the largest body of freshwater in BC. It has a mean depth of 44 m, a maximum depth of 166 m, a mean annual drawdown of 11 m, a flushing rate of 19 months and is composed of three large arms, or reaches (Peace, Parsnip and Finlay), named after the major rivers that were inundated.

The pelagic zooplankton population in Williston Reservoir has a diverse species assemblage, with a seasonal (June to October) density of 6.5 • L^{-1} and biomass of 22 µg • L^{-1}, in 1999. Average density values at each site ranged from 3-4 • L^{-1} at the Junction and Parsnip reaches, 5-6 • L^{-1} at the Peace and Finlay reaches, to the largest population of 14.6 • L^{-1} near the dam forebay. The population density averaged 88% copepods and 11% cladocerans, and biomass averaged 56% and 44%, respectively, with some variability between sites. Fifteen species of macrozooplankton were identified in the samples, with copepods such as *Diaptomus ashlandi* and *Cyclops bicuspidatus thomasi*, and the cladoceran *Daphnia galeata mendotae* among the more numerous.

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INTRODUCTION

This report summarizes zooplankton data collected in 1999 as part of the Williston Reservoir monitoring program. This is the first year of a projected two year study initiated to establish the current limnology and trophic status of Williston Reservoir by assessing reservoir physical, chemistry and biological data. The study will compare current results with previous Williston Reservoir limnological studies, where possible, to determine if the trophic level of the reservoir is changing. Changes in the reservoir's productivity, or trophic status, will have implications to fisheries resources. This study is the genesis of a proposed long term monitoring program that will be replicable in perpetuity. The analysis of current Williston Reservoir zooplankton populations is presented in this report and forms an integral component of the overall Williston Reservoir monitoring program (Stockner and Langston 2000).

Williston Reservoir was created in 1968 by damming (W.A.C. Bennett Dam) the Peace River for hydroelectric generation, creating the largest body of fresh water in British Columbia. The reservoir has a surface area of 1,779 km^2 at the maximum normal operating elevation of 672.1 m (BC Hydro 1988), a dendritic shoreline of 1,770 km (BC Research 1977), and a mean depth of 44 m with a maximum depth of 166 m (Fleming, et al. 1991, unpublished data). The reservoir has a storage capacity of 74,256.7 million cubic meters, the ninth largest in the world (Maclean 1998) and a flushing rate of 19 months (Hirst 1991). The reservoir stores spring snow melt run-off and annual rain fall from a catchment area of 69,930 km^2, an area equal to the size of the province of New Brunswick (McLean 1998). The reservoir cycles between maximum and minimum levels once per year, typically reaching a maximum level in August and September. Power generation in response to electricity demand is highest in the winter months resulting in increased discharges from the dam, and combined with low winter inflows result in dramatic winter drawdowns, which have averaged 11 m from 1984 to 1987 (Hirst 1991). Minimum reservoir levels are typically reached by the end of April.

The impoundment of the Peace River and creation of Williston Reservoir created a large waterbody where only rivers existed previously, and inundated approximately 1,700 km^2 of previously vegetated land. This created a sudden and dramatic release of nutrients, from inundated soil and vegetation, to the newly formed reservoir. This input of nutrients is finite, as eventually losses of nutrients from sediment adsorption, impaired littoral zone function and discharge at the dam outweigh inputs from natural sources and a process of oligotrophication begins. Barrett and Halsey (1985) referred to a pattern characteristic of "new" reservoirs whereby an "explosion" in population numbers of all trophic levels occurs in the first few years, followed by a significant decrease. The cycle of a temporary spike in productivity followed by a period of oligotrophication and eventual equilibrium at a "low" trophic level typically requires 20 to 25 years to occur (Stockner 1998).

The trophic status of Williston Reservoir is currently oligotrophic (Stockner and Langston 2000), but whether or not a stabilized equilibrium has been reached is unknown.

Numerous limnological studies (BC Research 1976, 1977; Barrett and Halsey 1985; Fleming et al. 1991 unpublished data; G3 1996) have collected data and reported upon water quality and trophic status. Considerable inconsistencies in factors such as locations of sample stations, depth and times at which samples were collected, parameters examined, analysis methodology, and laboratory detection limits reduce the amount of comparable data.

This project will establish permanent sampling stations and register them within the Environmental Monitoring System (EMS), which is administered by the Water Management Branch, Ministry of Environment, Lands and Parks. All collected data will be available to any future researchers that access the database, which should encourage future researchers to sample at these sites as well, providing valuable data for future comparisons.

This year one (1999) report is primarily a status report with brief analysis of the results and minimal comparisons to previous studies. A comprehensive analysis, and assessment of current trophic status of Williston reservoir will be presented in a final report, along with a synthesis of collected biological, chemical and physical limnological data, in addition to primary productivity experiments which are scheduled for year two (2000) of the study.

Study Area

Williston Reservoir (56° N latitude, 124° W longitude) is located approximately 140 km north of Prince George in north-east British Columbia, Canada (Fig. 1). The reservoir was formed following the 1968 impoundment of the Peace River by the W.A.C. Bennett Dam near Hudson's Hope, British Columbia. Approximately 22 km downstream of the W.A.C. Bennett Dam a second dam (Peace Canyon Dam), impounds water to the base of the W.A.C. Bennett Dam creating Dinosaur Reservoir. Dinosaur Reservoir is operated as "run of the river" hydroelectric project, and water released to the Peace River flows east to Lake Athabasca of the MacKenzie River drainage system. The MacKenzie then flows north and discharges into the Arctic Ocean.

The W.A.C. Bennett Dam inundated the upper Peace River approximately 120 km (creating the Peace Reach) west to its origins, the confluence of the Parsnip and Finlay rivers. From the confluence, the Finlay River was inundated (forming the Finlay Reach) in a north-west direction approximately 120 km and the Parsnip River was inundated in a south-east direction (forming the Parsnip Reach) approximately 110 km (Fig. 1).

The vastness of the watershed encompasses five biogeoclimatic zones: sub-boreal spruce, sub-alpine Engleman Spruce sub-alpine fir, boreal white and black spruce, spruce-willow-birch and alpine tundra (BC Hydro 1988). The Omineca mountains to the west, and Rocky mountains to the east contain the generally north to south oriented Finlay and Parsnip rivers within the Rocky Mountain Trench. These two reaches of the reservoir are contained within a wide and

often flat-bottomed valley, where glacial deposition, moraines and lacustrine deposits are common (Fleming et. al. 1991, unpublished data). Glacial till is the most abundant surficial deposit found within the planning unit (Ministry of Environment 1983). The Peace Reach has a "V" shaped bottom and is much narrower and deeper than the Finlay and Parsnip reaches. Steep sloped sedimentary rock is predominant in the entrenched western half of the Peace Reach where the Peace River originally (prior to impoundment) cascaded east through the Rocky Mountains. The eastern half of the Peace Reach extends into the Rocky Mountain Foothills and contains lower gradient topography and geological features similar to the Finlay and Parsnip reaches.

The Williston watershed is subject to long cold winters. Temperatures of -30° C can occur anytime after October with sub zero temperatures often extending into April, however, frost may occur at any time of the year (McLean 1998). Ice formation on the Reservoir can begin as early as November, though complete coverage does not usually occur until January. Ice cover can be delayed, as occurred during the winter of 1999 - 2000, or even incomplete in uncommonly warmer than normal winters. The dam forebay is generally the last area to freeze. Ice cover normally extends to approximately the first week of May, with the Finlay Reach generally the last area be completely "ice free". The summer maximum average temperatures range from 16° C to 18° C, with maximum temperatures reaching 30° C (G3 1994). Williston Reservoir is dimictic, and stratification is weakest and shortest in duration in the shallower Finlay and Parsnip reaches as opposed to the deeper Peace Reach.

Annual precipitation averages 400 - 500 mm in the majority of the watershed, with 750 - 1000 mm precipitation in the Rocky mountains east of the Finlay Reach (BC Hydro 1988). Snowfall accounts for 35 to 45% of the annual precipitation.

Zooplankton Methods

Macrozooplankton samples were collected from five stations (Table 1, Fig. 2) established as part of the Williston Reservoir monitoring program (Stockner and Langston 2000). Stations are located within the lacustrine zone (as defined by Thornton 1990) of each unique and distinct basin of the reservoir; Finlay Reach, Parsnip Reach, and Peace Reach stations. Additionally, two stations of special interest have been established; the "Junction" and the "Forebay" stations. The Junction station is situated near the origin of the Peace Reach and represents a transition/ mixing zone where Finlay and Parsnip waters are integrated and begin flowing east. The Forebay station is located approximately 2 km upstream from the W.A.C. Bennett Dam. A secondary site selection criterion included proximity to past research sampling locations, positioning over the original inundated river channels, and distancing from input sources (river mouths, and sluffmg banks) of nutrients and water. Additionally, a nutrient sampling only station is located on the Peace River (left bank) 500 m downstream of the Peace Canyon Dam.

Table 1. Stations sampled for zooplankton as part of the Williston Reservoir monitoring program in 1999, their EMS (Environmental monitoring system) numbers and UTM co-ordinates.

sample station	EMS #	UTM co-ordinates
Dam Forebay	234188	10.550204.6210540
Peace Reach	234186	10.486000.6204000
Junction	234187	10.452000.6211550
Finlay Reach	234184	10.410111.6252000
Parsnip Reach	234185	10.458200.6175500

Sampling occurred monthly at each station between May and November of 1999 (June-Oct for Finlay because of ice cover). At each station, duplicate macrozooplankton samples were collected with a vertically (0-30 m) towed 80-µm mesh Wisconsin plankton net with a 50 cm throat diameter, and a 74 µm mesh window for straining water from the collection cup. The net was raised at a speed of approx. 0.5 $m \cdot sec^{-1}$, and the samples preserved with 70% ethanol. Samples were analyzed for species composition, density, biomass, and fecundity in the following manner. The total volume of the sample was measured, stirred, then split with a Folsom splitter to a volume which contained not less than 100 post naupliar stages of the most abundant taxa. A random subsample comprising a known proportion of the sample was then enumerated for species, size, sex, stage of maturity and reproductive condition. Fecundity of the dominant genera was estimated by counting the number of eggs of the first ten gravid females counted. Enumeration was conducted on a gridded petri-dish using GSZ Zeiss stereo-microscope under suitable magnification (10-100 times). Additional examination of crucial body parts was done using an inverted microscope and magnification up to 400 times. The entire sample was also examined for large organisms (such as *Leptodora kindti*) that are not efficiently subsampled.

Adult calanoid copepods were identified using Wilson (1959), and adult cyclopoids following Yeatman (1959). Cladoceran identifications followed Brooks (1959) and Deevey and Deevey (1971), but with the observed *Eubosmina longispina* resembling those described by Brooks as *Bosmina coregoni*.

Biomass estimates were made by first measuring body length (to the nearest 0.01 mm) for a maximum 10-15 individuals from each group (male, female, gravid female, copepodite, nauplii) present in the sample. Cladoceran body length was measured from the anterior end of the carapace to the base of the tail spine. Copepods were measured from the anterior end of the metasome to the posterior end of the urosome, excluding the caudal rami. Lengths of individual zooplankter were then converted to body mass (µg dry weight) using length-weight relationships from McCauley (1984), developed for each species. If an equation was not listed for a species an equation from a similarly shaped species was used, and those substitutions were as follows; The equation for *Diaphanosoma brachyrum* was used for *D. leuchtenbergianum*, the equation for

Daphnia galeata was used for *D. longiremis*, the equation for *Diaptomus gracilis* was used for *Cyclops bicuspidatus thomasi*, *Heterocope septentrionalis* and *Epischhura nevadensis*, and the equation for *Diaptomus sicilis* was used for all the *Diaptomus* species. Species biomass was then computed from the number of individuals in each group multiplied by their arithmetic mean body mass.

Zooplankton Results

Abundance and Biomass

The pelagic zooplankton population in Williston Reservoir had a very diverse species assemblage, with a seasonal (June to October) density of 6.5 • L^{-1} and biomass of 22 µg • L^{-1}, but with a wide range in values between sites. Average density values at each site ranged from 3-4 • L^{-1} at the Junction and Parsnip reaches, 5-6 • L^{-1} at the Peace and Finlay reaches, to the largest population of 14.6 • L^{-1} at the Dam Forebay site (Table 2). Density peaked in July/August at values of 4-10 • L^{-1} at most sites, with the exception of the Dam Forebay site where density peaked at 25 • L^{-1} (Fig. 3). The average reservoir population composition was 88% copepods and 11% cladocerans, but again there was a wide range between sites. At their peak densities, cladocerans composed 22% (or 2.7 • L^{-1}) of the population at the Finlay Reach, and 1.4% (or 0.07 • L^{-1}) in the Peace Reach. Fifteen species of macrozooplankton were identified in the samples, with cosmopolitan species such as *Diaptomus ashlandi*, *Cyclops bicuspidatus thomasi*, and *Daphnia galeata mendotae* among the more numerous. Of note, there were three species of *Daphnia* and four species of *Diaptomus* identified, along with the rarely seen *Heteroscope septentrionalis*. Five species of rotifers (*Keratella quadrata*, *K. cochlearis*, *Polyarthra* sp., *Asplanchna* sp. and *Kellicottia* sp.) were also identified in the samples but are not addressed in this report. The large mesh size of the net (80-µm) used would not capture most of the rotifers and, therefore, any density values given would largely underestimated the true population.

Copepods were numerically the dominant macrozooplankton group in Williston Reservoir, averaging 88% of total zooplankton density and 56% of biomass. The largest copepod population, averaging 13.5 • L^{-1}, was found at the Dam Forebay site with copepod densities ranging from 2-5 • L^{-1} at the other sites (Table 2). Copepod densities peaked in August at most stations, except the Finlay Reach and Junction sites where densities peaked in June (Fig. 4). *Diaptomus* was the dominant copepod, which is typical of most water bodies (Wilson and Yeatman 1956), and with an average density around 4 • L^{-1} was the most numerous genera of zooplankton captured, especially at the Dam Forebay and Peace Reach sites. Four species of *Diaptomus* were found with *D. pribilofensis* the most numerous, accounting for approx. 70% of the *Diaptomus* density. The other *Diaptomus* species in order of abundance were *D. ashlandi*, *D. sicilis* and *D. denticornis* (Fig. 5). *Cyclops* was the only cyclopoid copepod identified and was the second most numerous copepod and zooplankton genus captured, at an average density of 1.6 • L^{-1}. Of the two *Cyclops* species captured, *C. scutifer* was the more numerous with

populations peaking at 0.1-1 • L^{-1} in late-July, and *D. bicuspidatus* peaked slightly later in the summer at densities no greater than 0.25 • L^{-1} (Fig. 6). Several *Heterocope septentrionalis* were captured in mid-summer at each station (densities <0.003 • L^{-1}). They are large individuals which are rarely captured, especially in pelagic tows, and were probably captured near the bottom of the 30 m deep tows used in this project (D. Dolecki, UBC Dept, of Zoology, pers. comm.).

Table 2. Seasonal (June-Oct.) macrozooplankton genera captured, average abundance and biomass in Williston Reservoir, 1999.

species	Dam		Peace		Junction		Finlay		Parsnip	
	# • L^{-1}	µg • L^{-1}	# • L^{-1}	µg • L^{-1}	# • L^{-1}	µg • L^{-1}	# • L^{-1}	µg • L^{-1}	# • L^{-1}	µg • L^{-1}
Cladocera										
Eubosmina longispina	<0.01	<0.01	<0.01	0.01	<0.01	0.01	0.26	0.82	0.01	0.04
Diaphanosoma leuchtenbergianum	0.02	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Leptodora kindtii	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Daphnia spp.	1.04	13.4	0.07	1.90	0.46	7.70	1.09	21.0	0.42	6.0
Holopedium gibberum	<0.01	1.22	0.01	0.99	0.01	1.72	<0.01	1.01	0.01	1.14
Total Cladocera	1.06	13.5	0.07	1.9	0.46	7.7	1.34	21.8	0.44	6.1
Copepoda										
Cyclops spp.	2.37	4.58	1.49	3.40	1.62	3.07	1.24	2.61	1.33	2.85
Heterocope septentrionalis	<0.01	0.06	0.02	1.06	0.03	1.05	<0.01	0.01	<0.01	0.08
Epischura nevadensis	0.01	0.10	0.01	0.12	<0.01	0.06	0.01	0.10	0.01	0.11
Diaptomus spp.	11.14	16.08	3.54	9.72	1.98	3.74	3.45	6.99	0.86	2.50
Total Copepoda	13.5	20.8	5.1	14.3	3.6	7.9	4.7	9.7	2.2	5.6
Total zooplankton	14.6	34.4	5.1	16.2	4.1	15.6	6.1	31.6	2.6	11.6

Cladocerans were occasionally captured in May (when sampling began) and June, but significant populations did not develop until August (Fig. 7). Peak densities were generally 1-4 • L^{-1} (or 20-40% of the total density), with the highest single sample density (4.3 • L^{-1}) at the Dam forebay site (Fig. 7), but the highest average seasonal density (of 1.3 • L^{-1}) at the Finlay Reach (Table 2). Cladoceran densities were low at the Peace Reach site compared to the others as the cladoceran density remained <0.25 • L^{-1}. Despite their low abundance compared to copepods, cladoceran biomass generally peaked at 15-20 µg • L^{-1} (Fig. 8), or approx. 65% of total biomass, with an average of 44% of the June to October biomass. As with density, there was some noteworthy variation in biomass between sites. Cladoceran biomass was very low at the Peace Reach (ave 1.9 µg • L^{-1}), peaked at 50 µg • L^{-1} at the Dam site (but averaged only 13.6 µg • L^{-1}), while in the Finlay reach populations were less variable but had the highest average of 21.8 µg • L^{-1} (Table 2, Fig. 8).

Five genera of cladocerans were identified in the samples (Table 2). *Daphnia* were the dominant cladoceran genera, accounting for approximately 96% of cladoceran density (and 70% of biomass), except in the Finlay Reach where *Eubosmina* populations peaked at 1 • L^{-1}, or 20% of cladoceran densities (Fig. 7). Three species of daphnia were found, with *D. galeata mendotae*

the dominant, numerically accounting for 88% of the daphnia and 82% of the cladoceran density, with *D. pulex* and *D. longiremis* densities averaging about the same at 0.35 • L^{-1} (Fig. 9). The other cladoceran species had average densities < 0.05 • L^{-1} (Table 2), ranging from 1-5% of cladoceran densities.

In comparison to other large interior BC lakes and reservoirs, Williston Reservoir has a low zooplankton density, but with an average proportion of cladocerans (Table 3). The seasonal zooplankton density in Williston was 6.5•L^{-1}, similar to the Arrow density of 7•L^{-1} (Pieters et al. 1998), and considerably less than the Kootenay whole lake average which has fluctuated between 17-23•L^{-1} in 1992-1997 (Ashley et al. 1999), and Okanagan average which has fluctuated between 7-24•L^{-1} in 1997-99 (Wilson in: Andrusak et al. 2000). Okanagan and Kootenay lakes are at the more productive end of the oligotrophic trophic level. In contrast, total zooplankton density in Alouette Reservoir, a coastal reservoir bordering on ultra-oligotrophic productive conditions, is < 2•L^{-1} (Wilson et al. 1999).

Cladocerans accounted for approx. 12% of the total zooplankton density in Williston Reservoir, which is above their percentages in Kootenay and Okanagan Lakes (Table 3). The latter two all have established mysid populations which prey heavily on plankton, specifically cladocerans (Grossnickle 1979, Bowers 1988).

Table 3. Comparison of seasonal (approx. May - Oct.) total density of zooplankton, # of species captured, cladoceran and daphnia as percent of total zooplankton, and mysid abundance in Williston Reservoir and four other BC lakes/reservoirs (see text for sources).

lake/reservoir (year)	seasonal total density (# • L^{-1})	# of species	% cladocerans	% daphnia	Mysid density[a] (#•m^{-2})
Kootenay (1992-96)	17-23	11	9 %	7 %	131
Okanagan (1997-99)	7-24	8	5 %	1.5 %	212
Arrow (1998)	7	12	21 %	9 %	48
Williston (1999)	6.5	15	12 %	10.6 %	0
Alouette (1998)	<2	9	20 %	<< 1 %	0

[a] Kootenay in 1996, Okanagan in 1999, ave. of upper and lower Arrow in 1998, Kalamalka in 1998.

Zooplankton data was collected in September and November of 1976 from the Peace Reach (BC Research 1977). They only reported six species captured and five of those were also collected in 1999. The total abundance reported for September, 1976 was 2.2 • L^{-1}, similar to the 1999 abundances of 4.0 • L^{-1} collected in August and 2.1 • L^{-1} collected in October. The 1976 daphnia density of 0.29 • L^{-1} was also similar to the 0.20 • L^{-1} daphnia density collected in August of 1999, however, they reported only *Daphnia pulex*, and *D. galeata mendotae* was the dominant of three Daphnia species captured in 1999.

Fecundity and Size

The fecundity (proportion of gravid females) of the most common daphnia *(D. galeata mendotae)* fluctuated widely at each site but generally peaked in mid-summer, before their population peaked, at 50% (Fig. 10). The proportion of gravid females of *Cyclops scutifer* and *Diaptomus ashlandi* was more constant through the summer, each averaging about 35%. *Cyclops scutifer* fecundity peaked in mid-summer, along with their density, at 50%, while *Diaptomus ashlandi* peaked earlier in June/July. *Diaptomus pribilofensis* had a lower proportion of gravid females through the summer compared to the others, as it ranged from 5-10% (Fig. 10)

The sizes (body length) of the most common species appeared consistent at each site at between 1-1.5 mm, and they usually reached peak size in July/August (Fig. 11). *Heterocope septentrionalis* was by far the largest zooplankton species encountered, with typical sizes between 3.3-5 mm in length (Fig. 11).

Conclusion

In comparison with other British Columbia lakes, Williston Reservoir should be classified as oligotrophic based on zooplankton data collected in 1999.

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Figure 1. Williston Reservoir Watershed.

Figure 2. Location of sampling stations.

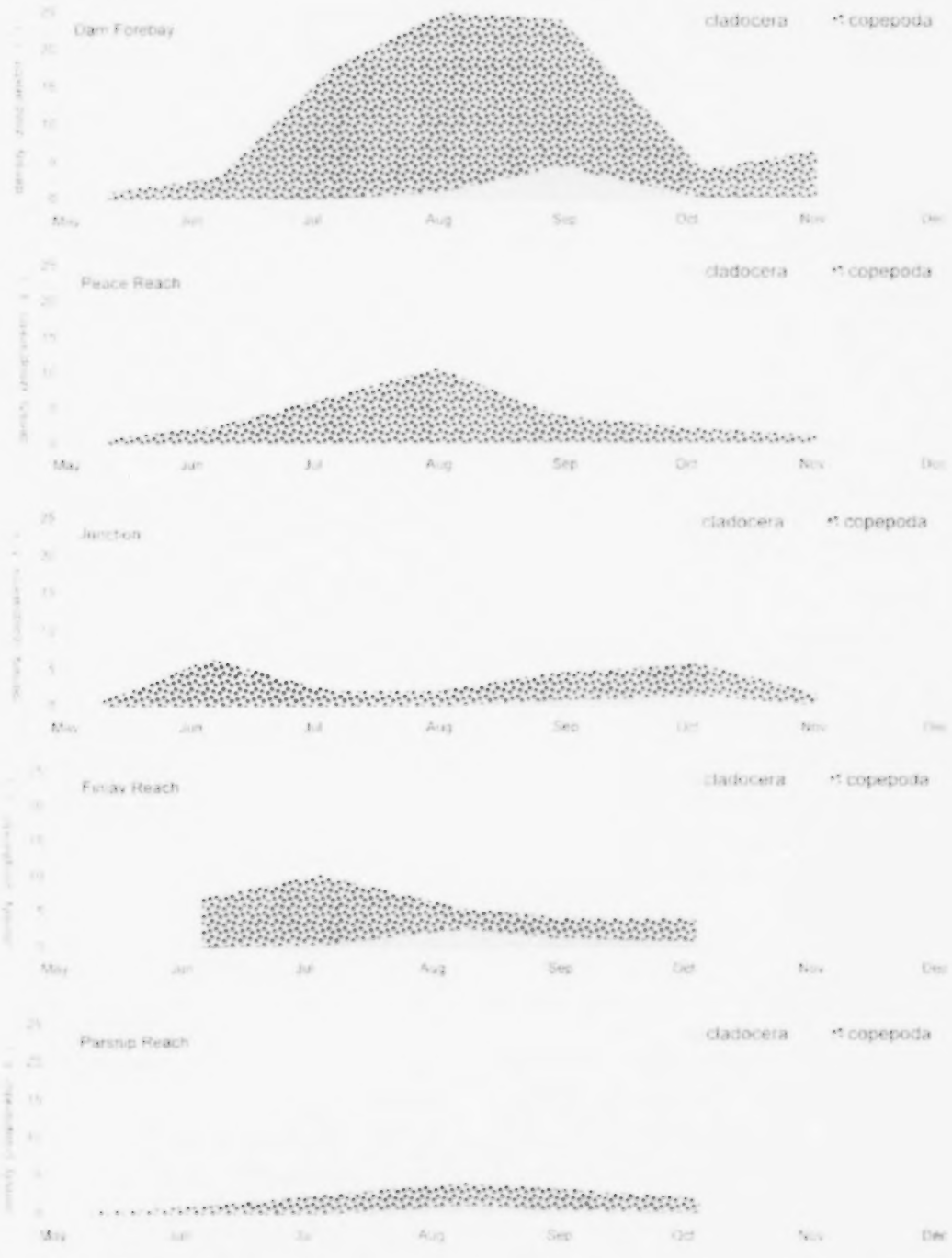

Figure 3. Density of cladoceran and copepod zooplankton in Williston Reservoir, 1999.

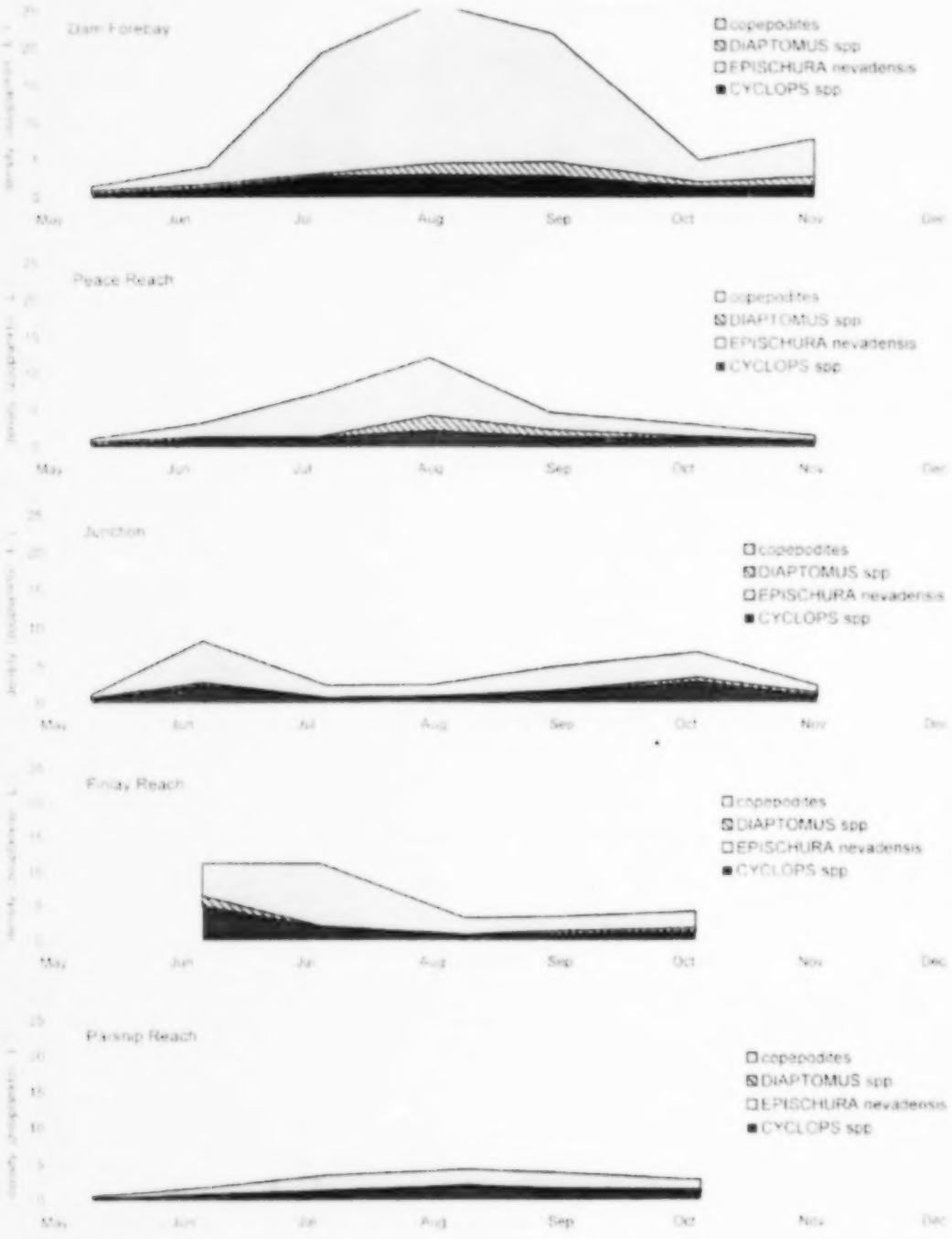

Figure 4. Density of major copepod zooplankton species in Williston Reservoir, 1999

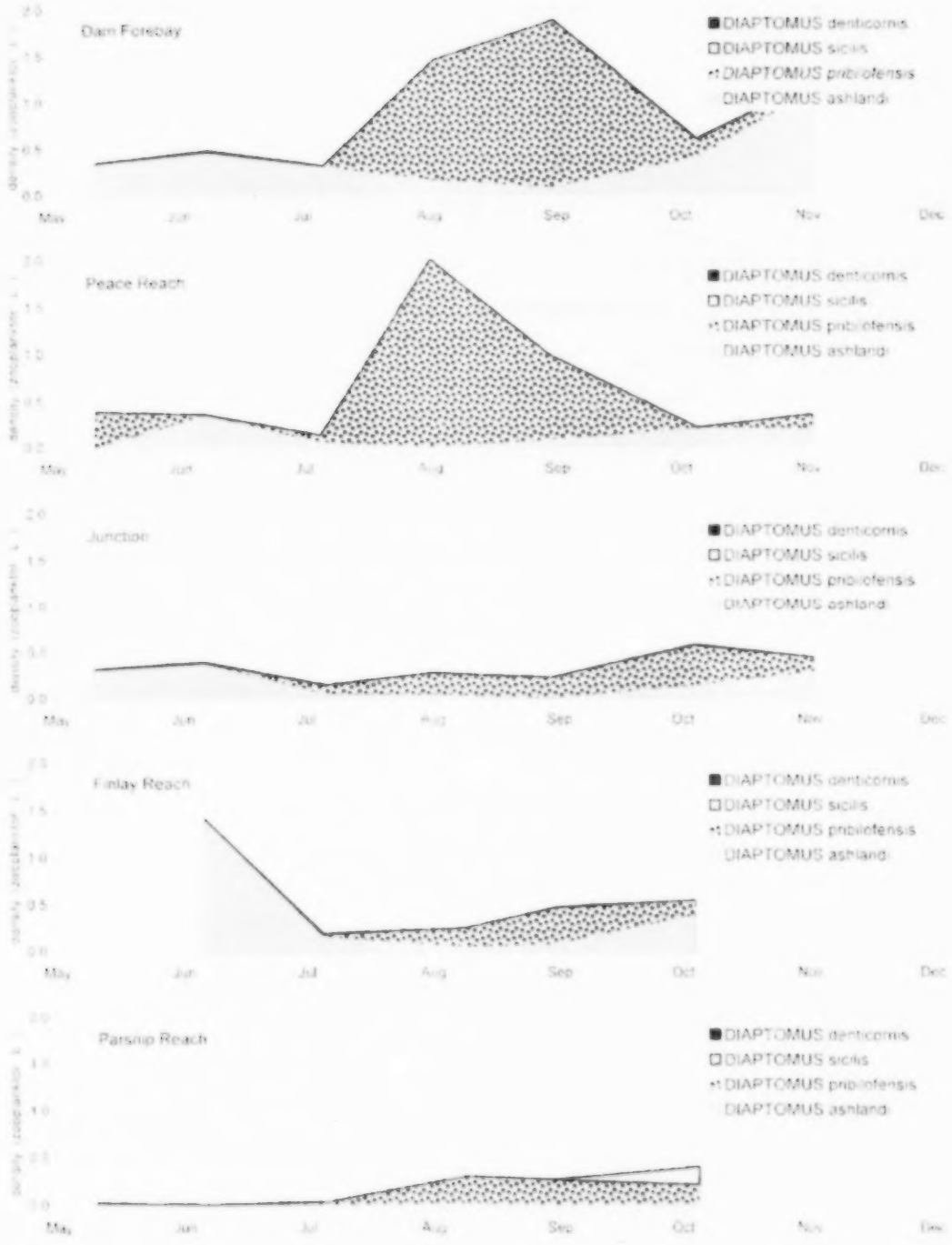

Figure 5. Density of *Diaptomus* species (excluding copepodites) in Williston Reservoir, 1999.

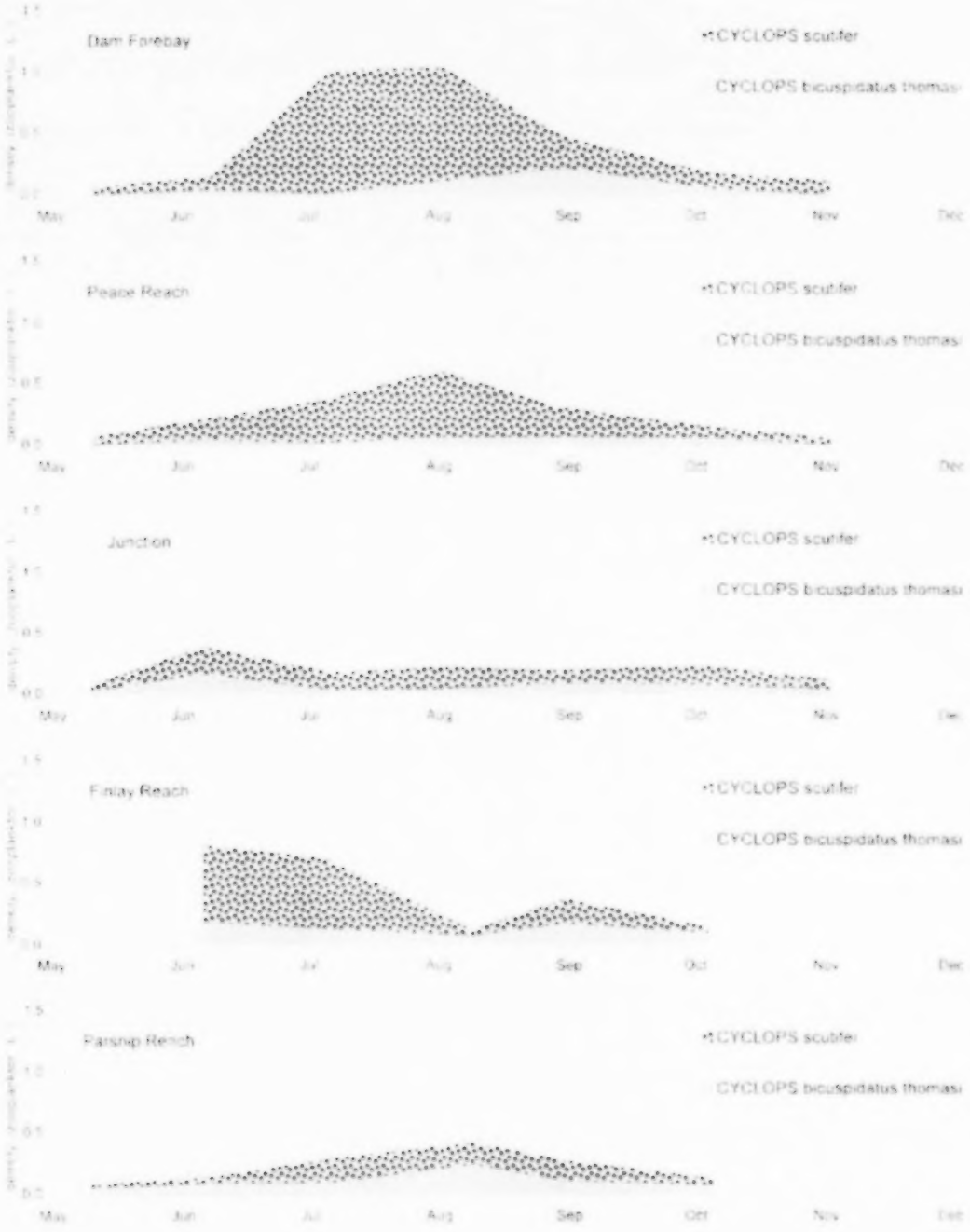

Figure 6. Density of *Cyclops* species (excluding copepodites) in Williston Reservoir, 1999.

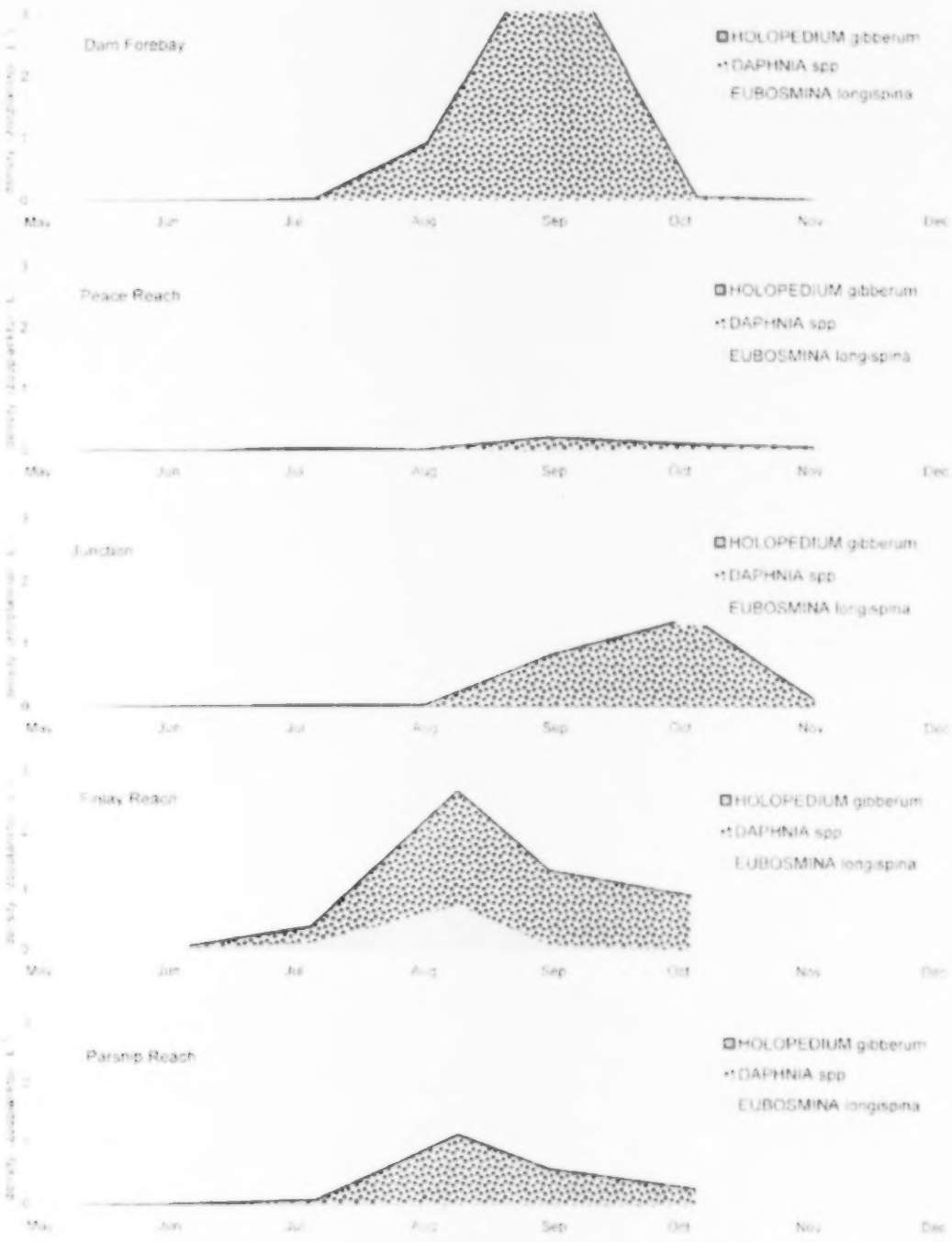

Figure 7. Density of major cladoceran zooplankton species in Williston Reservoir, 1999

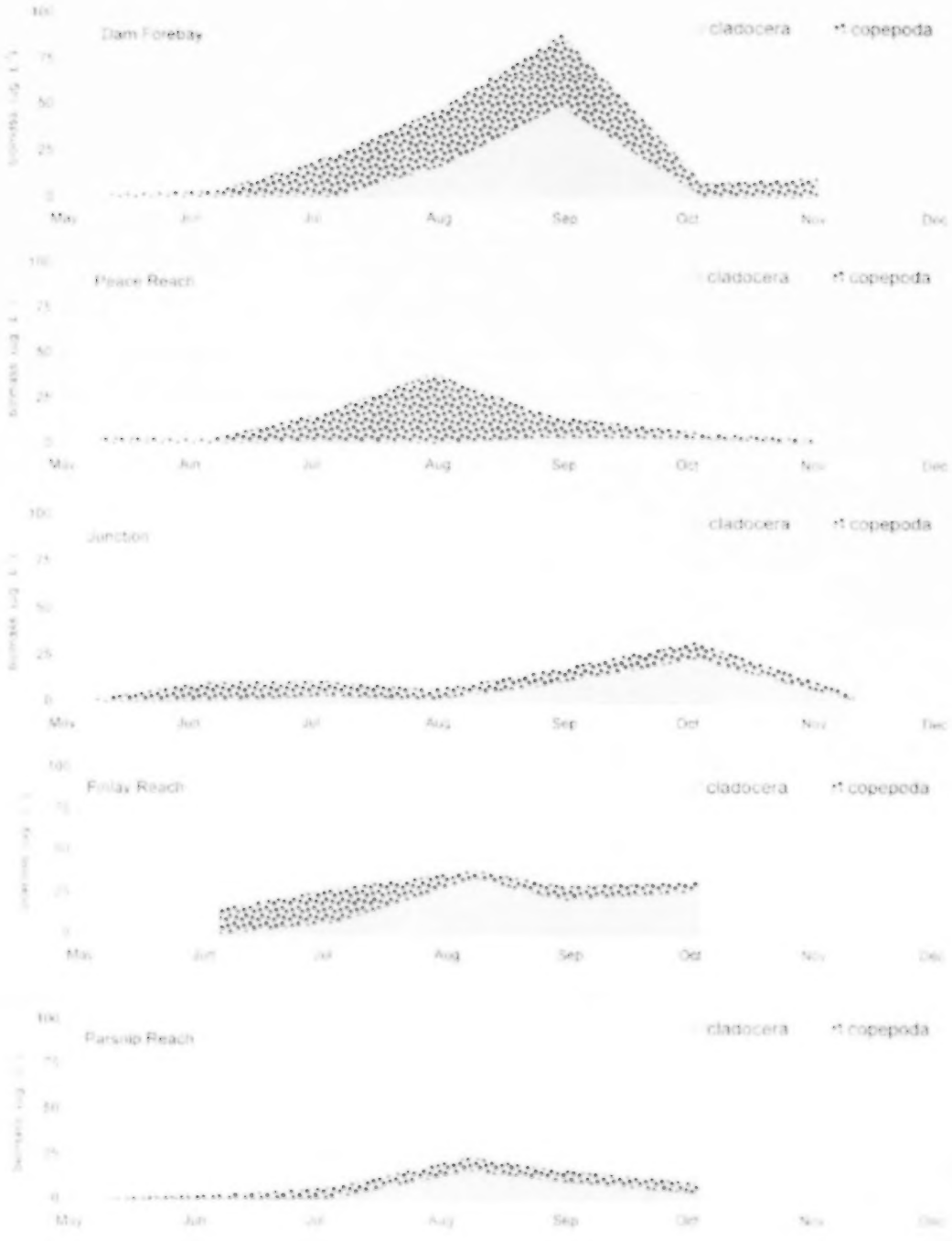

Figure 8. Biomass of cladoceran and copepod zooplankton in Williston Reservoir, 1999.

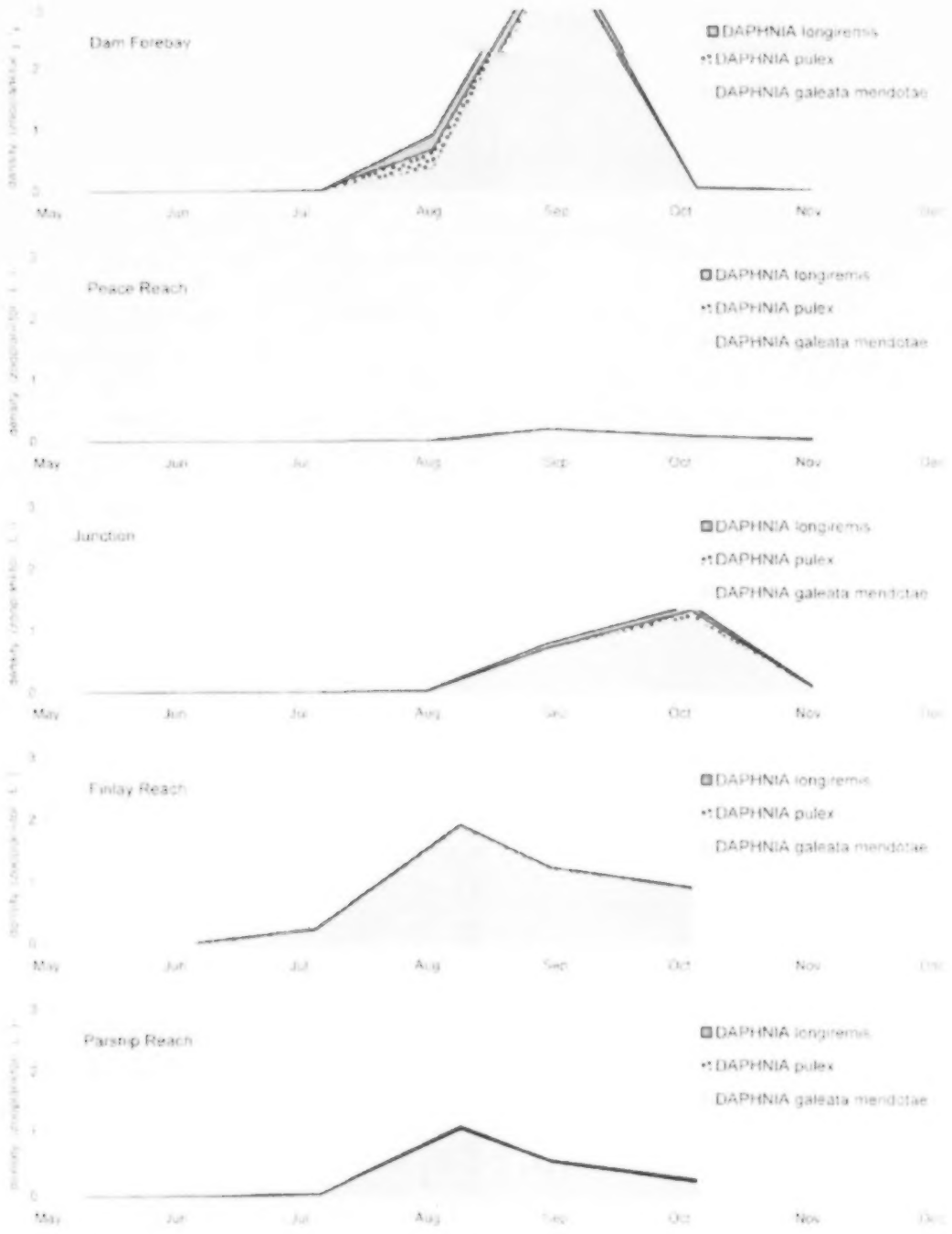

Figure 9. Density of *Daphnia* species (excluding copepodites) in Williston Reservoir, 1999.

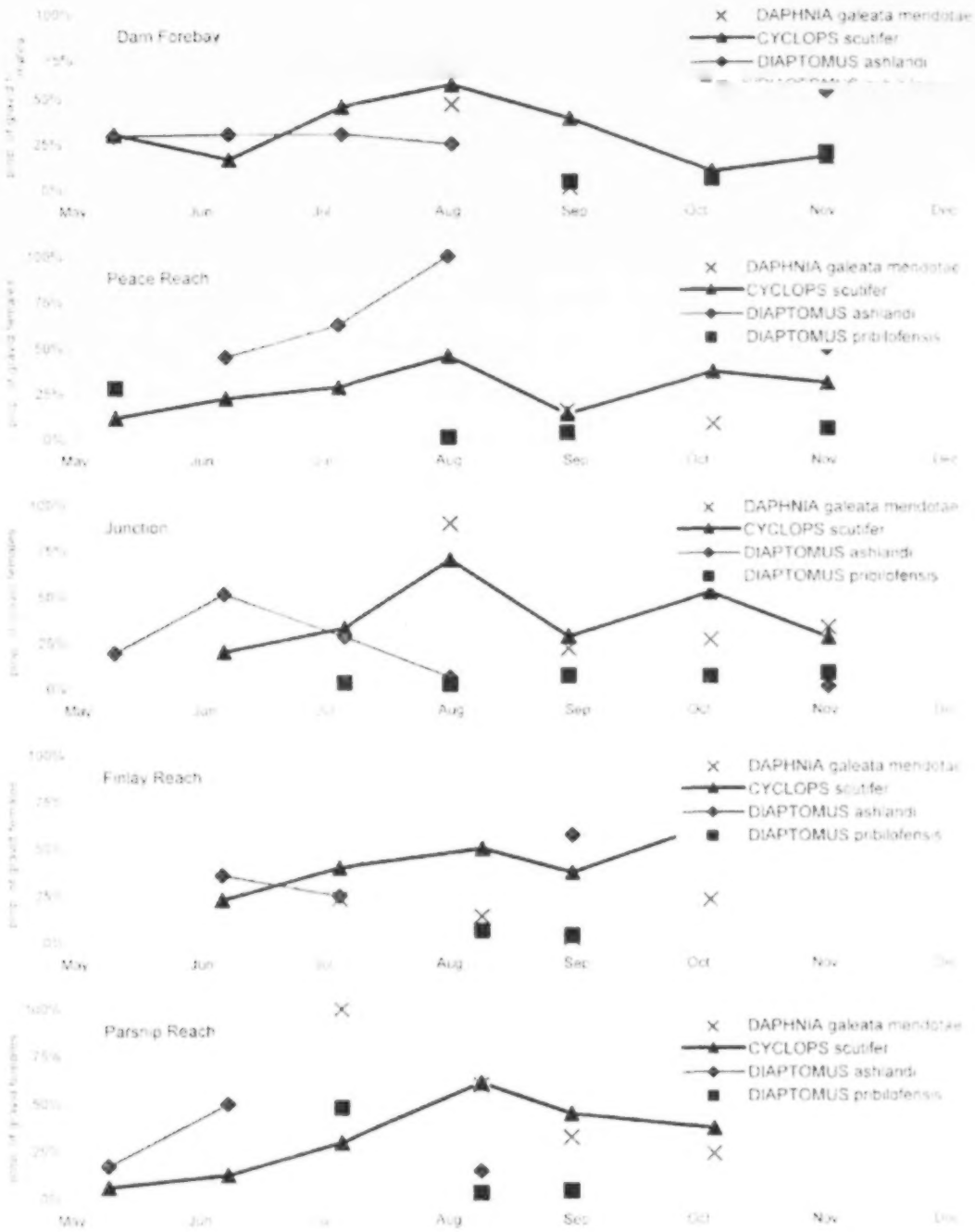

Figure 10. Fecundity (proportion of gravid females) from select genera of Williston Reservoir zooplankton, 1999.

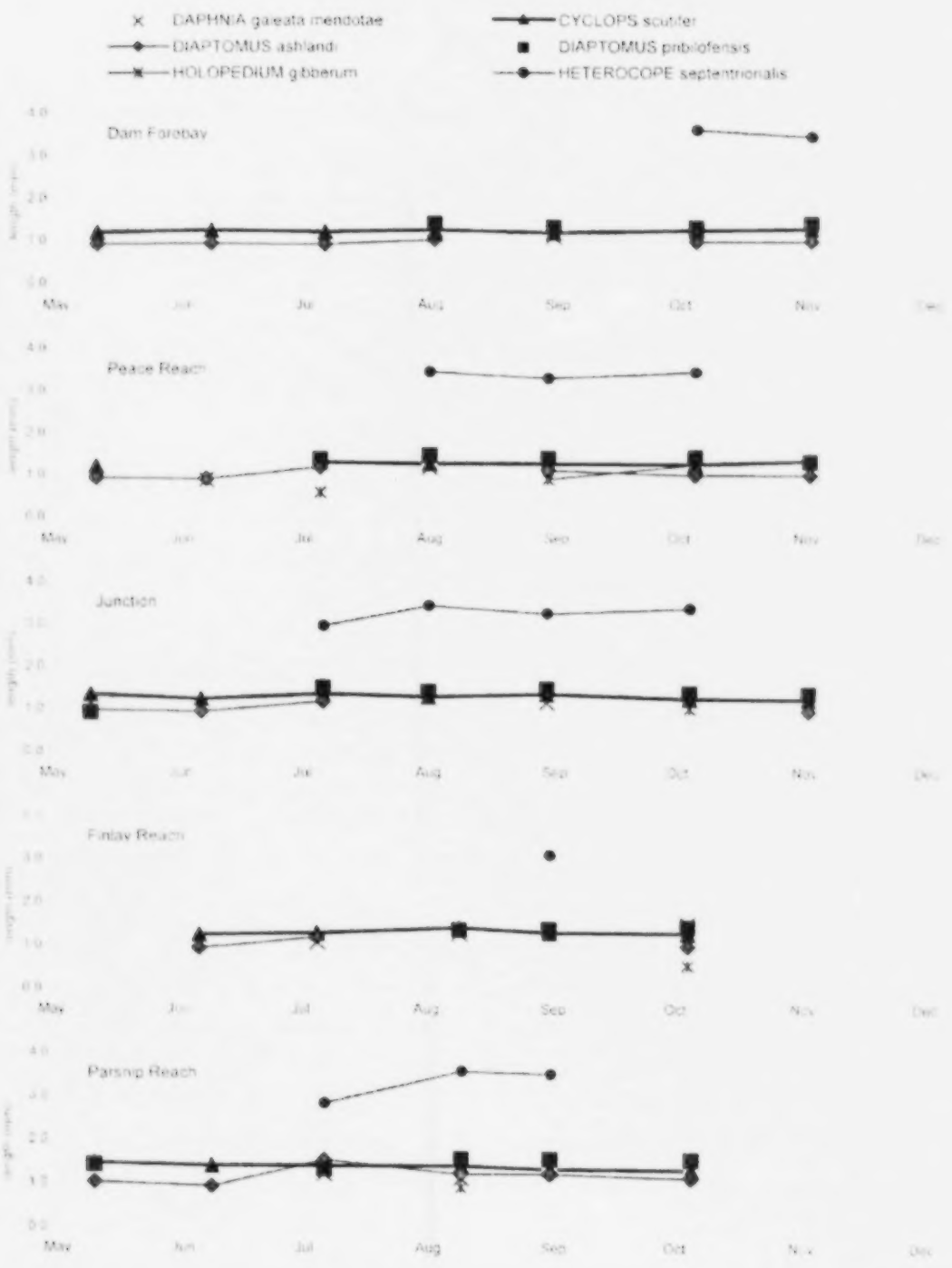

Figure 11. Average body length of the most common zooplankton species in Williston Reservoir